BASE ISOLATION & STRUCTURAL CONTORLS

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AAiT

CONTENTS

1. Introduction

- Catastrophic failures have occurred in civil engineering structures, such as buildings and bridges, during major seismic events.
  - At least 21,500 buildings structures and 71 bridge structures were damaged during the 1989 Loma Prieta EQ.
  - At least 20,000 building structures were damaged during the 1999 Izmit EQ.

1. Introduction

- Today, one of the main challenges in structural engineering is to develop innovative design concepts to better protect civil engineering structures, including their material contents and human occupants from these hazards.

1. Introduction

- Some of the mitigation measures
  - Conventional Approach
    - Designing the structure for strength and ductility
    - Selecting appropriate configuration
  - Innovative Approach
    - Mechanical systems are employed to reduce /control seismic demands.

1. Introduction

The conventional approach

- depends upon providing the building with strength, stiffness and inelastic deformation capacity which are great enough to withstand a given level of earthquake-generated force.

- is generally accomplished through the selection of an appropriate structural configuration and the carefully detailing of structural members, such as beams and columns, and the connections between them.

1. Introduction

Innovative Approach

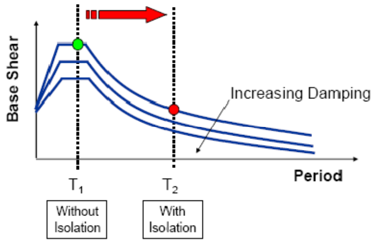
- In contrast, the basic approach underlying more advanced techniques for earthquake resistance is not to strengthen the building, but
- to reduce the earthquake-generated forces acting upon it.
- By de-coupling the structure from seismic ground motion it is possible to reduce the earthquake-induced forces in it. This can be done in two ways:
  - ✓ **Base isolation**
  - ✓ **Energy dissipating devices (Structural Controls)**

2. Base Isolation

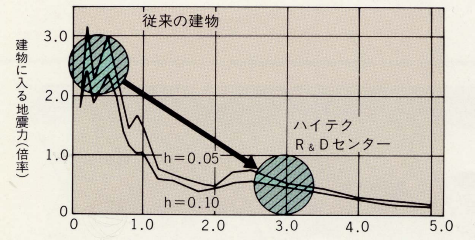
- Become practical since 1970
- Involves separation of upper structure from base or from the sub-structure by changing of a fixed joint with a flexible one.
- Involves inserting isolators

2. Base Isolation

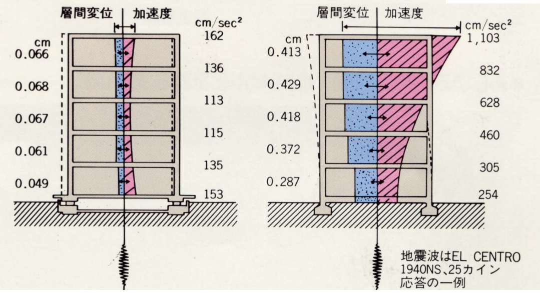
- Main Objectives:
  - By Shifting the vibration period to the long period range of the response spectrum.
  - By introducing some kind of 'fuse' between the structure and the ground.



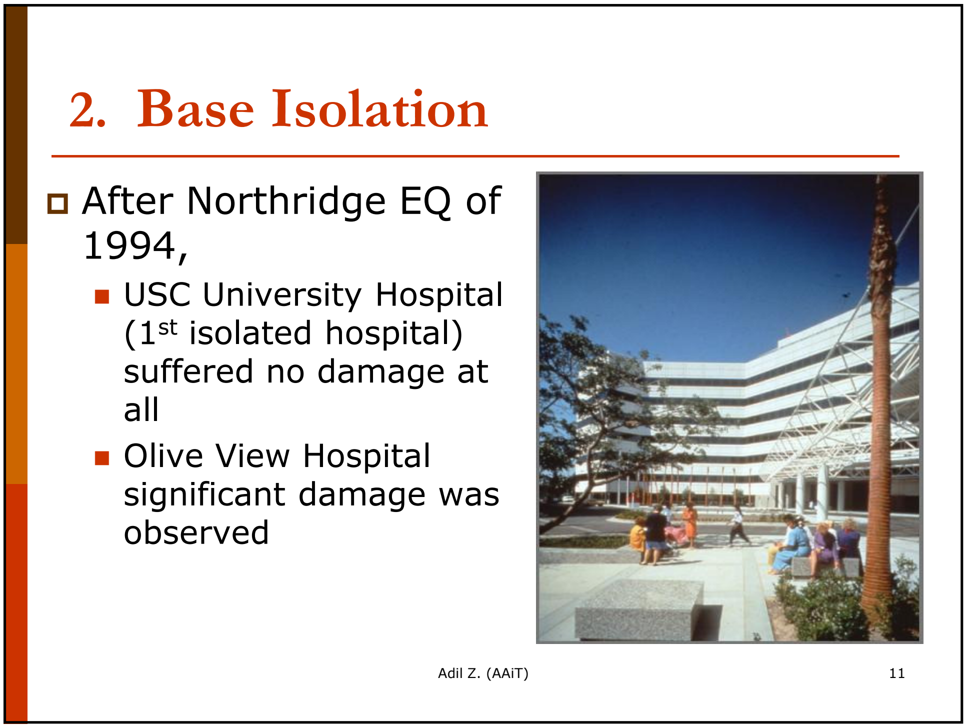
2. Base Isolation



- Seismic Acceleration Response Spectrum

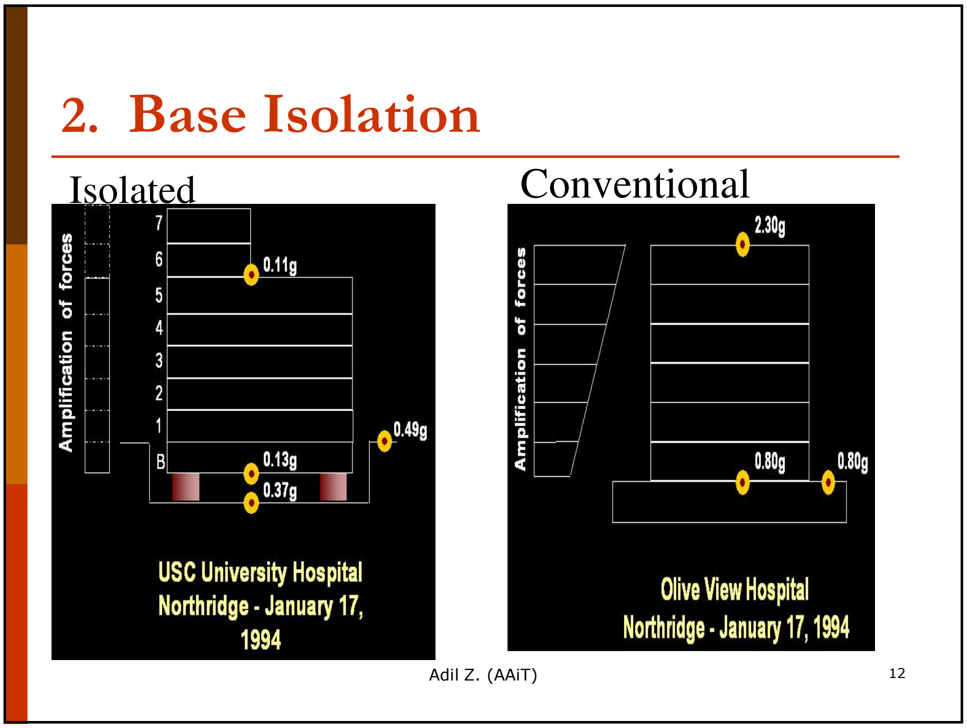


- Comparison of Seismic Response



2. Base Isolation

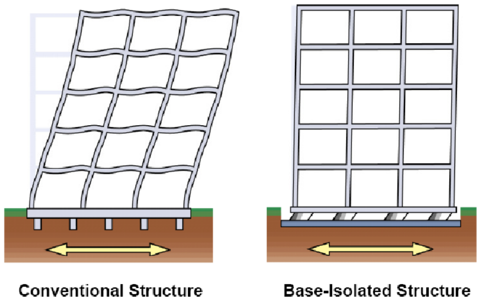
- After Northridge EQ of 1994,
  - USC University Hospital (1st isolated hospital) suffered no damage at all
  - Olive View Hospital significant damage was observed

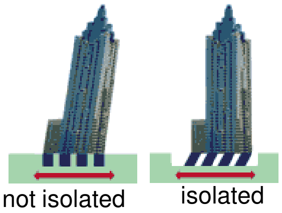


2. Base Isolation

2. Base Isolation

- **Seismic Base Isolation**





Refer to the following video clip

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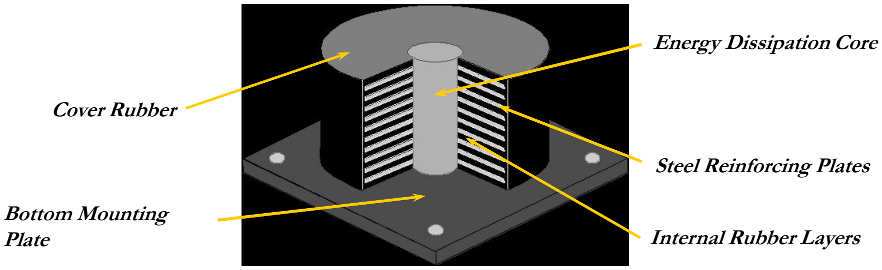
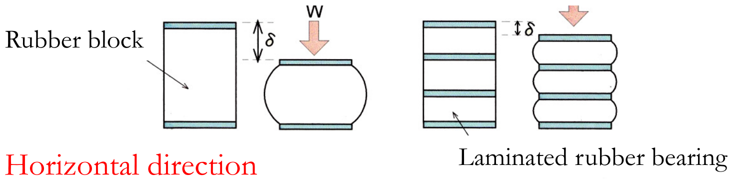
2. Base Isolation

- Common Seismic Base Isolation devices:
  - **Elastomeric bearings**
    - made from rubber typically in cylindrical or rectangular shapes
    - Lengthen the period of vibration

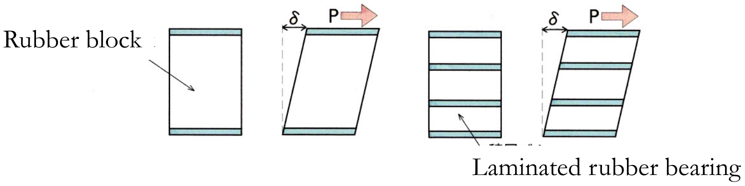


2. Base Isolation

1. Vertical direction



2. Horizontal direction



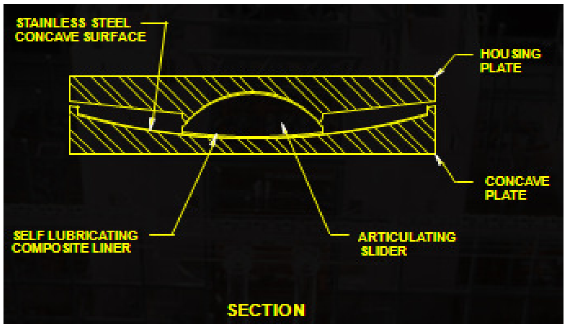
Principle of Laminated rubber bearing

2. Base Isolation

- Installation of elastomeric bearings

2. Base Isolation

- Common Seismic Base Isolation devices
  - **Sliding plates**
    - Reduce the force transferred from the superstructure to the supporting substructure by allowing the superstructure to slide on a low friction surface. E.g. **Friction bearing pendulum**



Typical friction bearing pendulum

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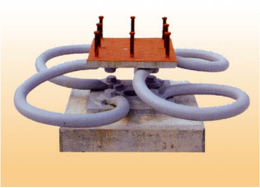
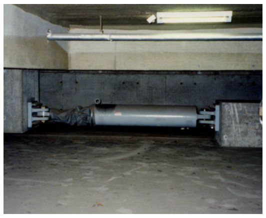
2. Base Isolation

Components of friction pendulum seismic isolator device for a large offshore structure

Other Base Isolation Devices

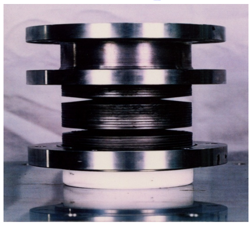


- Steel damper



- Oil damper

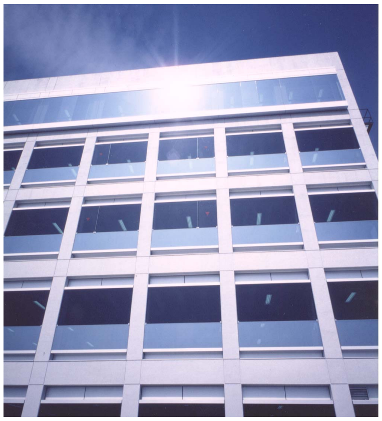
- Lead damper



- Friction damper with Coned disc springs

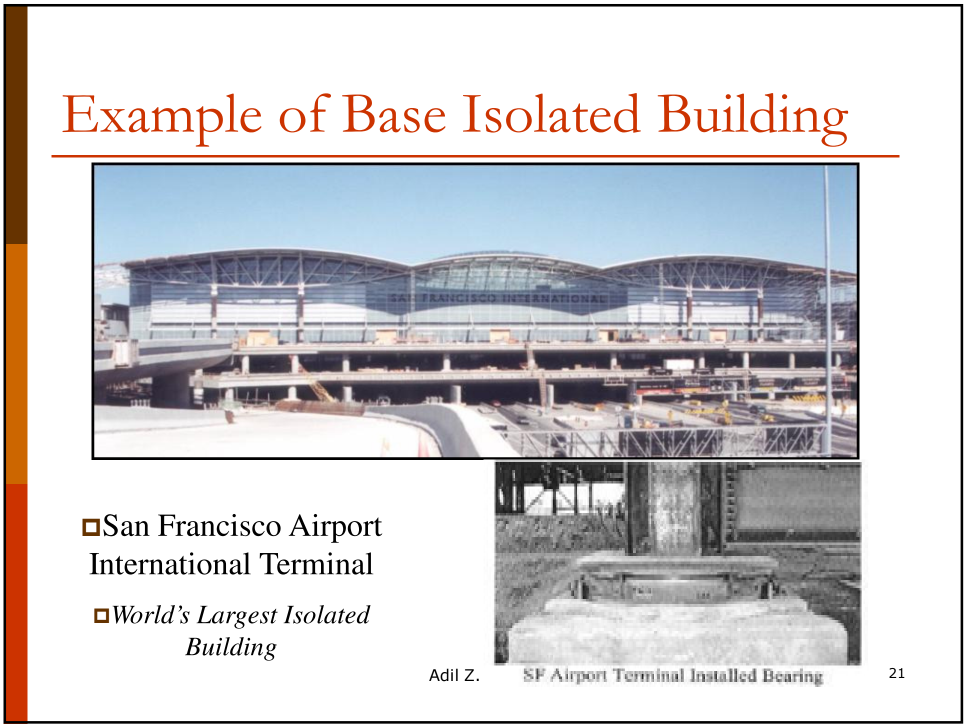
Example of Base Isolated Building

- Location : Tokyo
- Architect : Obayashi Corporation
- Structure : RC ; B1,5F
- Total floor area : 1,624 m^2
- Date of completion: August 1986



- Base Isolated Research Building

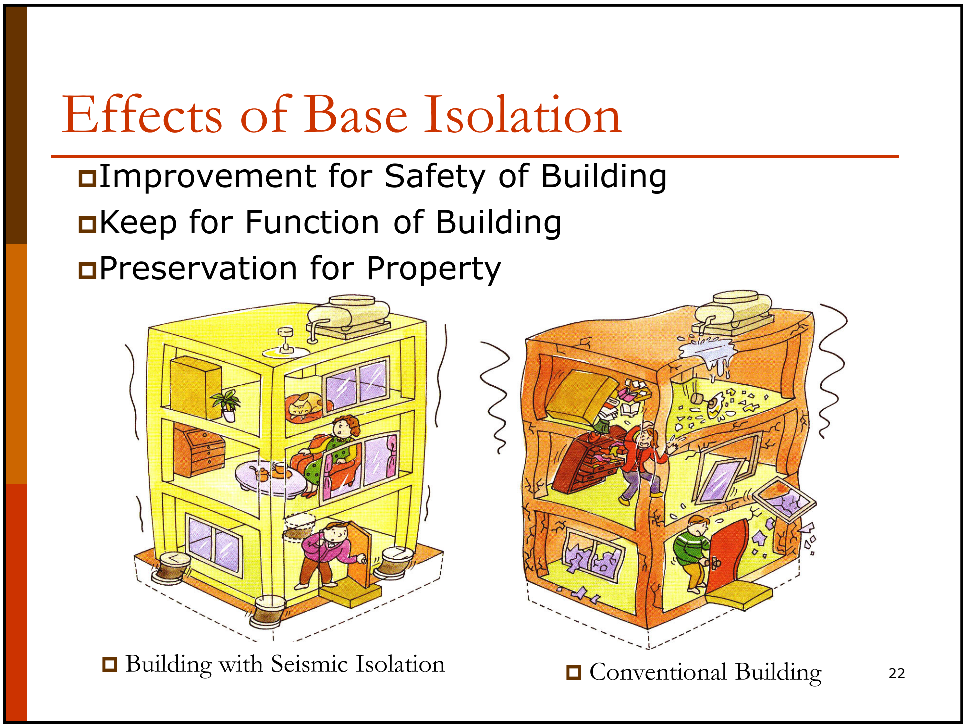
- Base Isolation Device



Example of Base Isolated Building

- San Francisco Airport International Terminal
  - *World's Largest Isolated Building*

SF Airport Terminal Installed Bearing



Effects of Base Isolation

- Improvement for Safety of Building
- Keep for Function of Building
- Preservation for Property

- Building with Seismic Isolation
- Conventional Building

Application of Base-Isolation

1) Government and Municipal Office,
Fire Station, Police Station,
Broadcasting Station

2）Hospital, Social welfare facilities

3）Laboratory

4）Computer Center

5）Museum, Gallery, Library

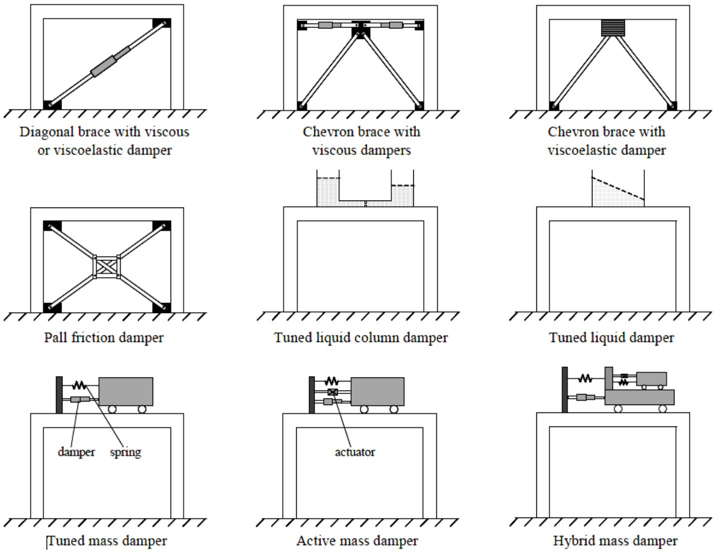
6）Apartment House

7）Cultural Asset, Historic Structure

3. Structural Controls

- Commonly used structural control / Energy Dissipating Device types:
  - Passive Control
  - Active Control
  - Hybrid Control
  - Semi-Active Control

3. Structural Controls



3.1. Passive Controls

- They are of two types:
  - Seismic base isolation (discussed in Section 2)
  - Passive energy dissipation devices
- Important features:
  - Operate without any external energy supply
  - Relatively inexpensive
  - compact and non-invasive to architectural spaces
  - Limits exist on the amount of control attainable

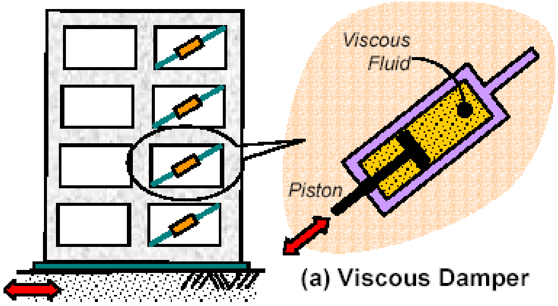
3.1. Passive Controls

Energy dissipation devices

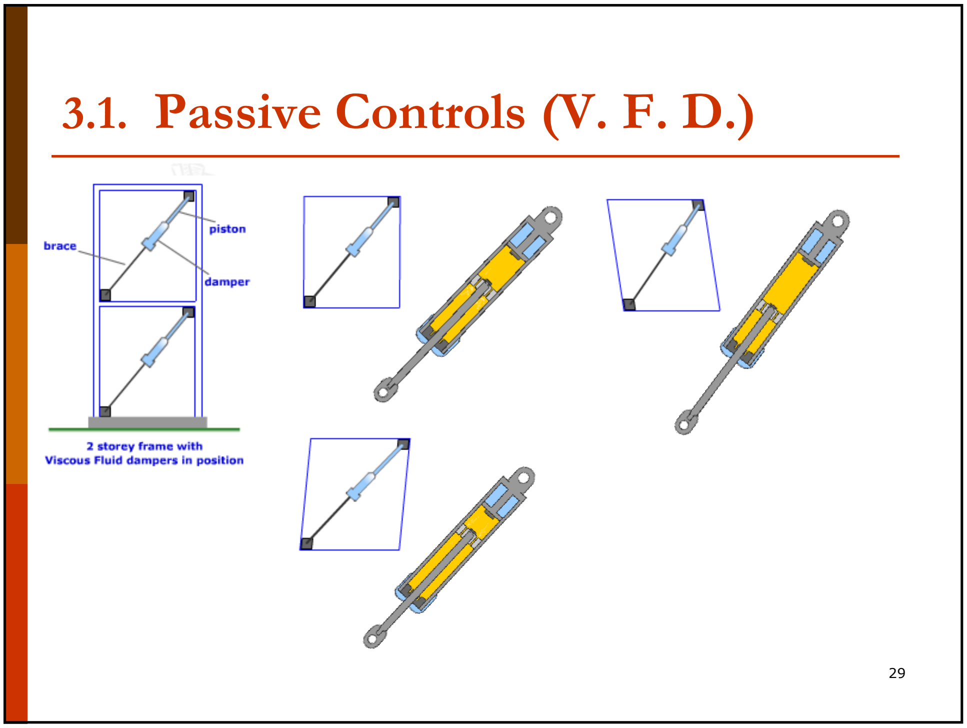
- Does not involve period elongation or fuse formation.
- Allows earthquake energy in to the building.
- Energy dissipation devices are located within the lateral resisting elements to intercept the incoming energy.
- The intercepted energy will be changed in to heat energy which will be dissipated in to the surrounding

3.1. Passive Controls (V. F. D.)

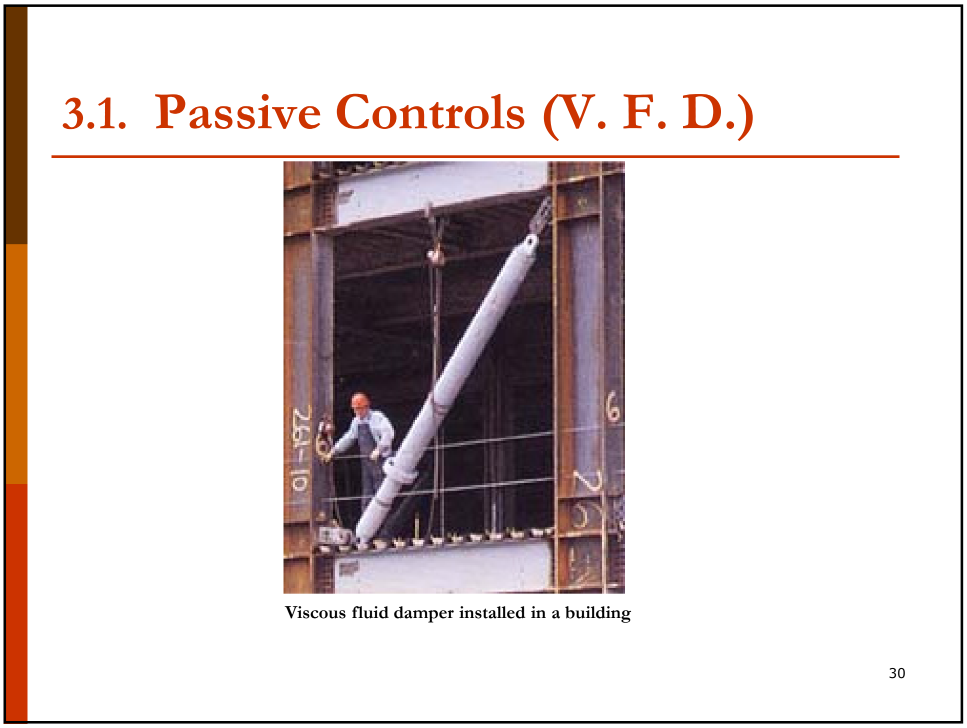
- Energy dissipation devices
  - **Viscous Fluid Dampers**
    - Dissipate energy by forcing a fluid through an orifice.



(a) Viscous Damper

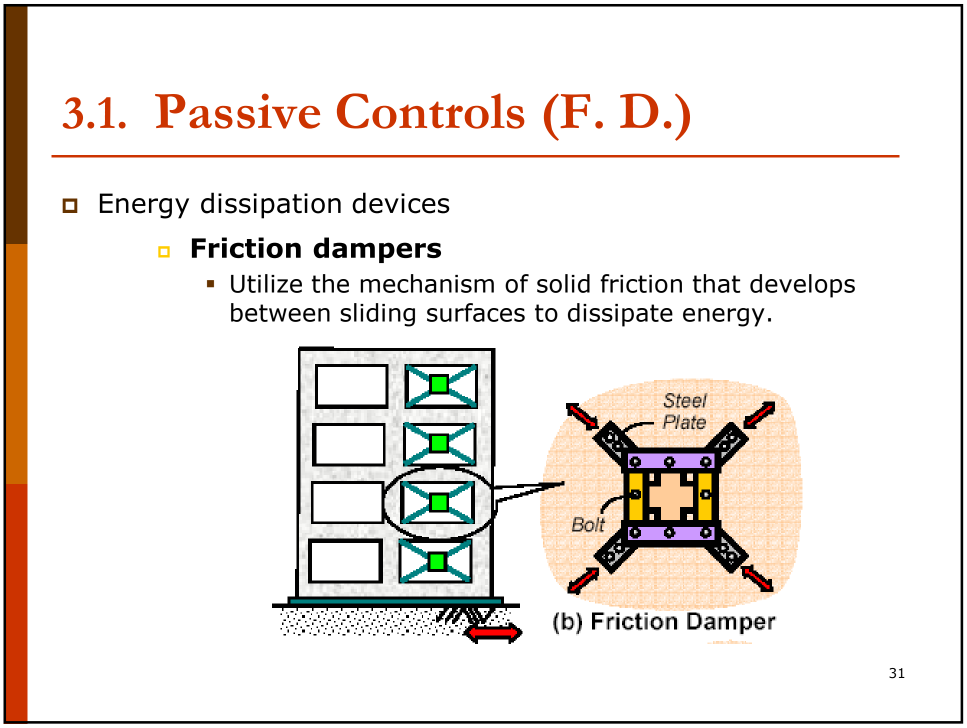


3.1. Passive Controls (V. F. D.)



3.1. Passive Controls (V. F. D.)

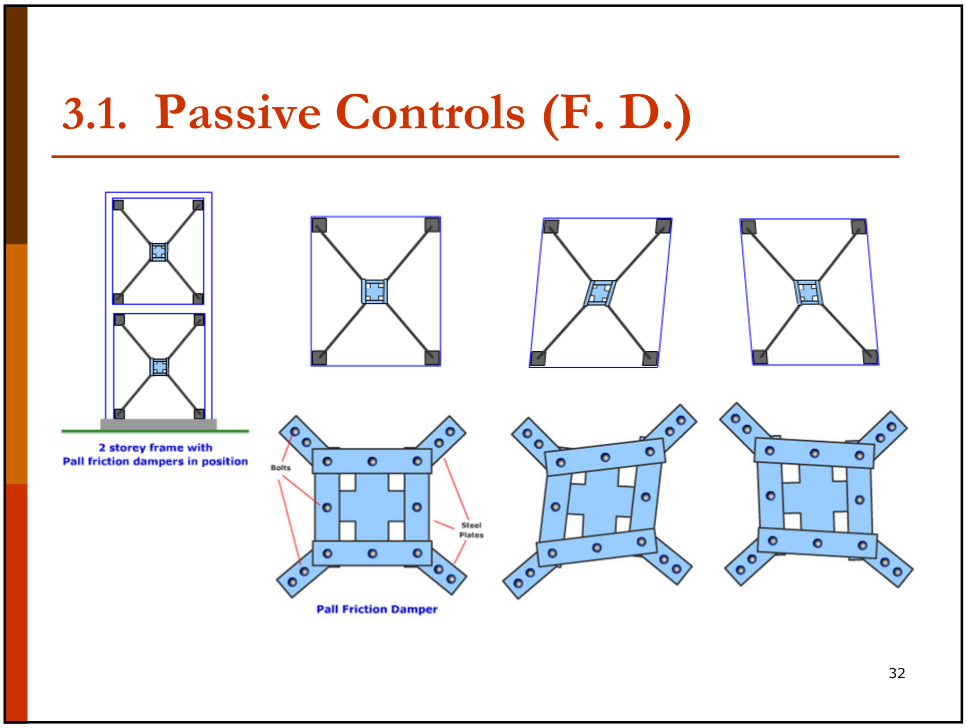
Viscous fluid damper installed in a building



3.1. Passive Controls (F. D.)

- Energy dissipation devices
  - **Friction dampers**
    - Utilize the mechanism of solid friction that develops between sliding surfaces to dissipate energy.

(b) Friction Damper

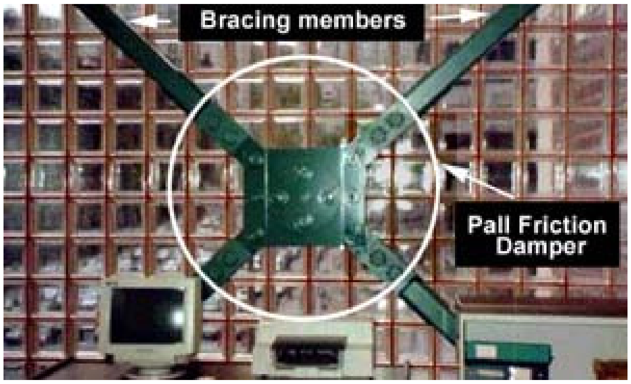


3.1. Passive Controls (F. D.)

2 storey frame with Pall friction dampers in position

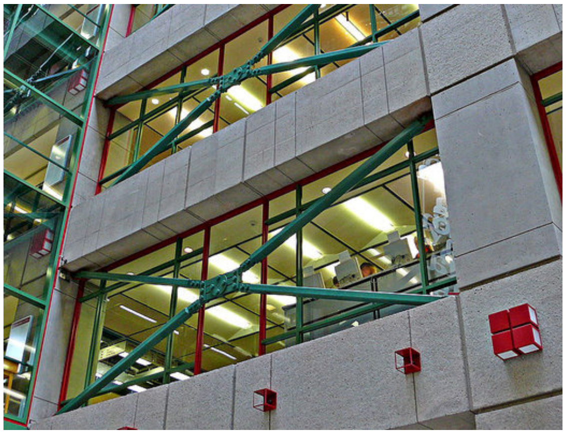
Pall Friction Damper

3.1. Passive Controls (F. D.)

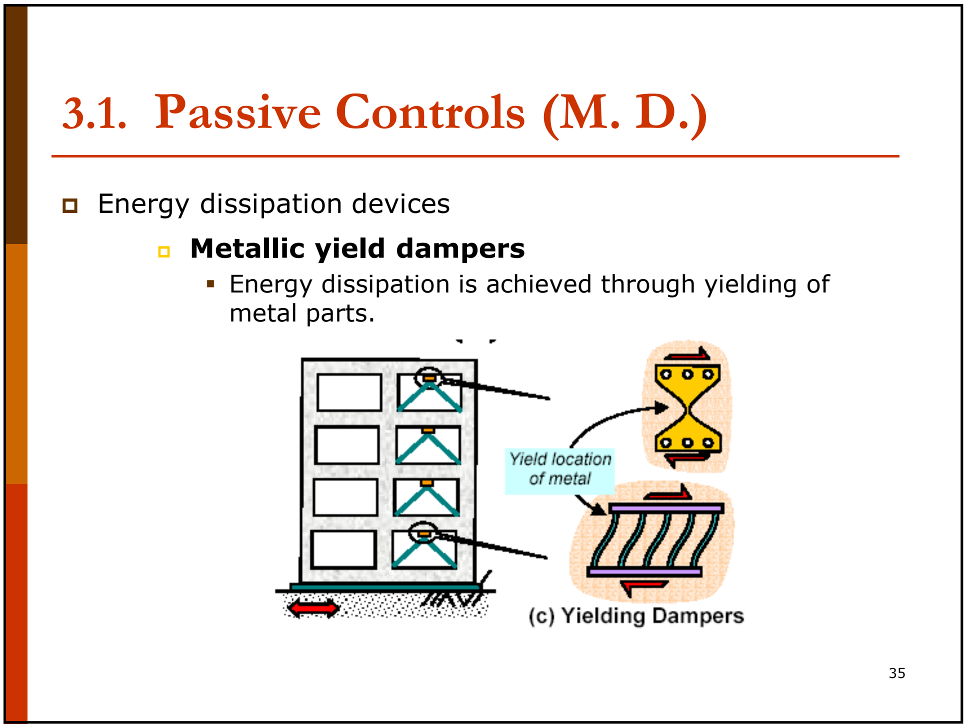


Pall Friction damper installed in a building

3.1. Passive Controls (F. D.)

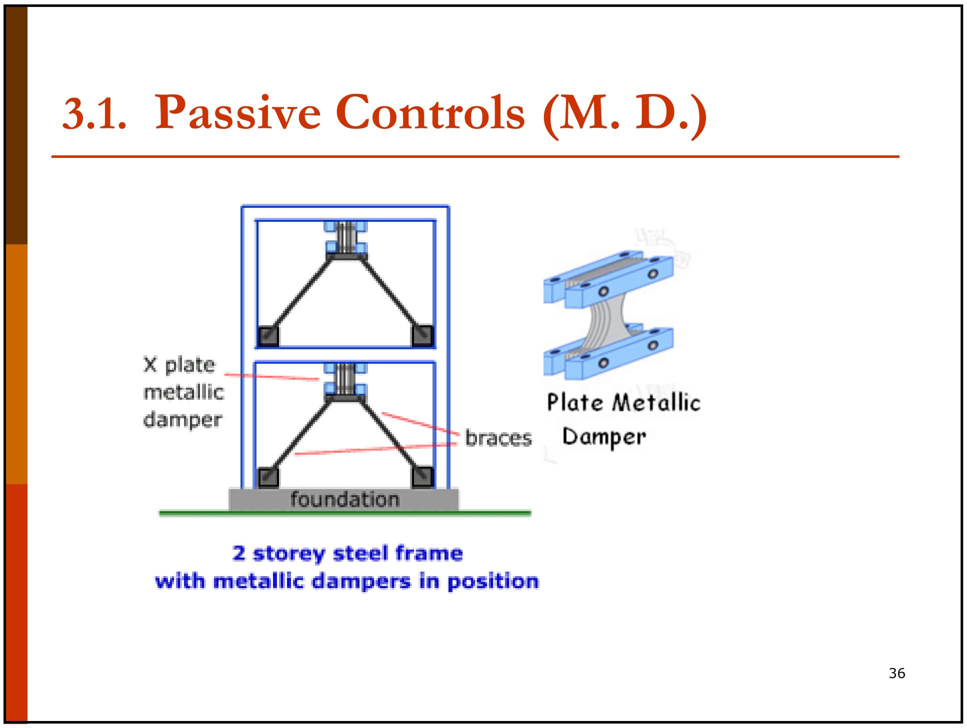


Pall Friction damper installed in a building



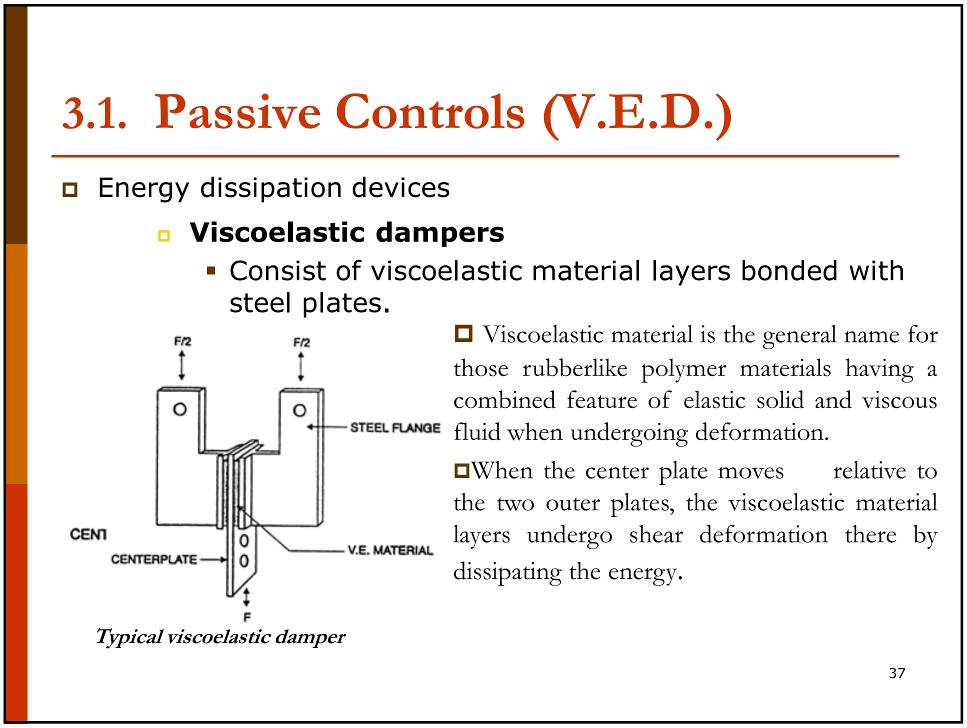
3.1. Passive Controls (M. D.)

- Energy dissipation devices
  - **Metallic yield dampers**
    - Energy dissipation is achieved through yielding of metal parts.



3.1. Passive Controls (M. D.)

2 storey steel frame with metallic dampers in position

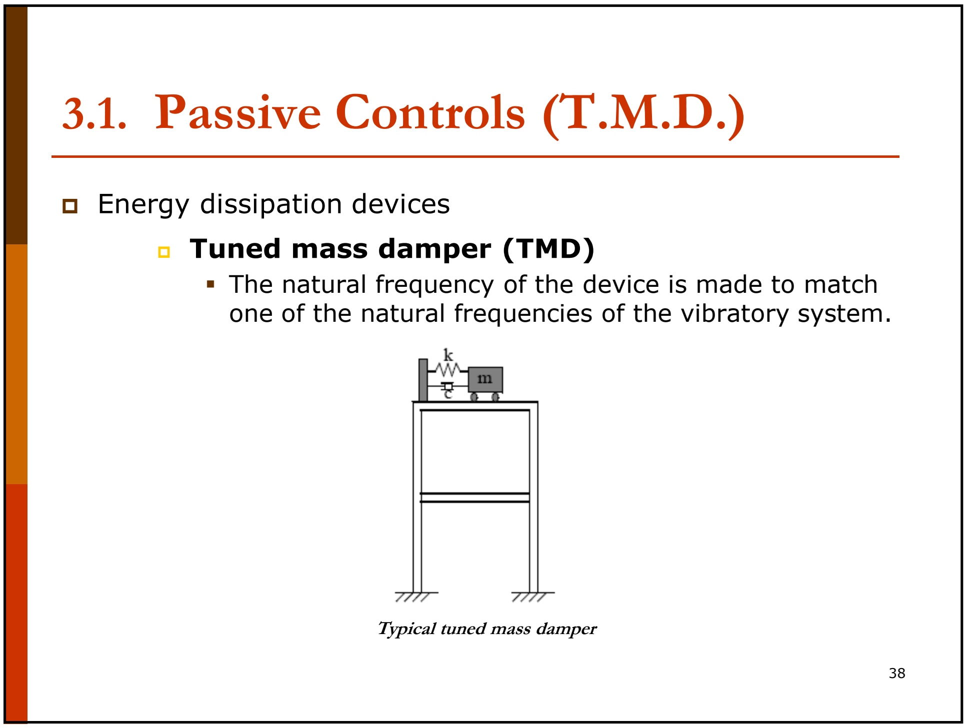


3.1. Passive Controls (V.E.D.)

- Energy dissipation devices
  - **Viscoelastic dampers**
    - Consist of viscoelastic material layers bonded with steel plates.

Typical viscoelastic damper

- Viscoelastic material is the general name for those rubberlike polymer materials having a combined feature of elastic solid and viscous fluid when undergoing deformation.
- When the center plate moves relative to the two outer plates, the viscoelastic material layers undergo shear deformation there by dissipating the energy.



3.1. Passive Controls (T.M.D.)

- Energy dissipation devices
  - **Tuned mass damper (TMD)**
    - The natural frequency of the device is made to match one of the natural frequencies of the vibratory system.

Typical tuned mass damper

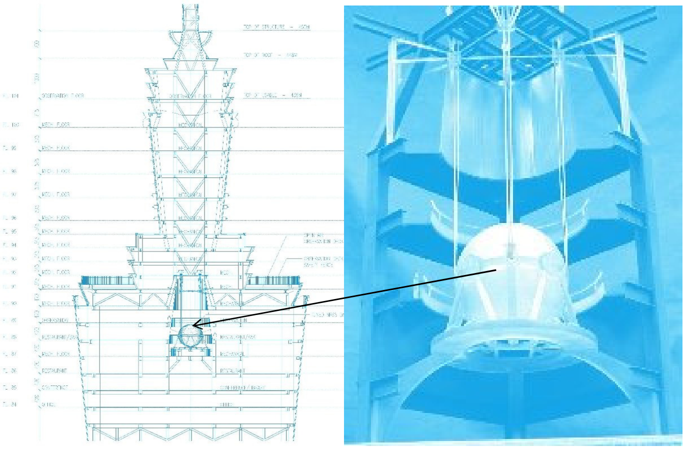
3.1. Passive Controls (T.M.D.)

Tuned mass damper atop the of Taipei 101.

Buiding Name	**Taipei 101**
Building Height	**508 m**
Location	**Taipei, Taiwan**

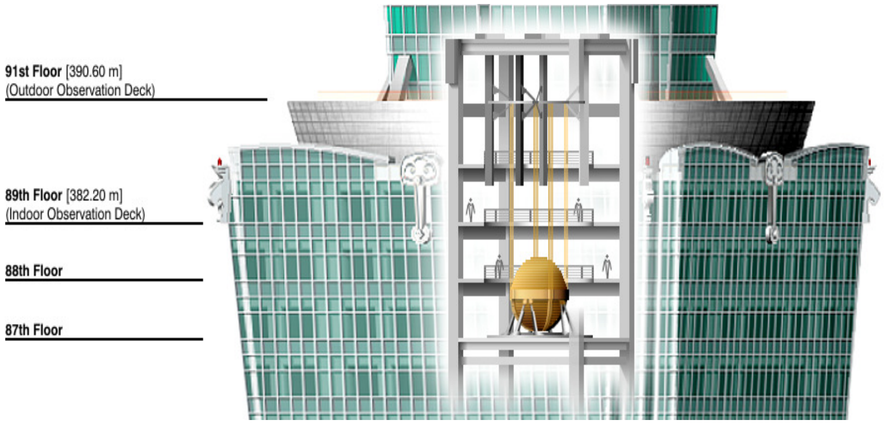
Taipei 101 has been the world's tallest building during 2004 - 2010

3.1. Passive Controls (T.M.D.)



TMD installed inTaipei 101

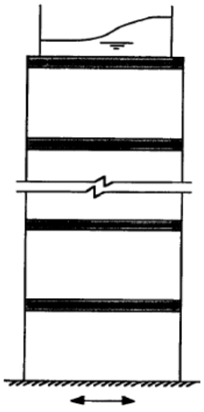
3.1. Passive Controls (T.M.D.)



TMD installed inTaipei 101

3.1. Passive Controls (T.L.D.)

- Energy dissipation devices
  - **Tuned Liquid Damper (TLD)**
  - The natural frequency of the fluid is made to match one of the natural frequencies of the vibratory system.
  - TLD absorbs structural energy by means of viscous actions of the fluid and wave breaking.



A building with a tuned liquid damper

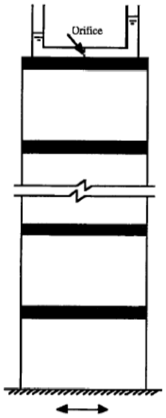
3.1. Passive Controls (T.L.D.)

- TLDs consist of rigid tanks filled with shallow liquid, where the sloshing motion absorbs the energy and dissipates it through viscous action of the liquid wave breaking and auxiliary damping appurtenances such as nets or floating beads.
- Advantages associated with TLDs include low initial cost, virtually free of maintenance and ease of frequency tuning, reduction of motion in two direction simultaneously and small stoke length.

- Please refer to the following video clip

3.1. Passive Controls (T.L.C.D.)

- Energy dissipation devices
  - **Tuned Liquid Column Damper (TLCD)**
  - TLCD are a special type of TLDs relying on the motion of the liquid column in a U-tube to counteract the forces acting on the structure, with damping introduced in the oscillating liquid column through an orifice.
  - A better dissipation rate can be achieved by adjusting the liquid column length.
  - Damping can also be increased by adjusting the orifice opening.



A building with a tuned liquid column damper

3.1 Shortcoming of Passive Tuned Dampers

- They are large in size when tuned to low frequencies
- They are single frequency (narrow band) treatments. When multiple frequencies need to be treated, a number of tuned absorbers/dampers should be used. This takes away from the simplicity and small size/mass attributes of the device.
- They are rather sensitive (absorbers more than dampers) to accurate tuning, and lose effectiveness when detuned.

3.2. Active Controls

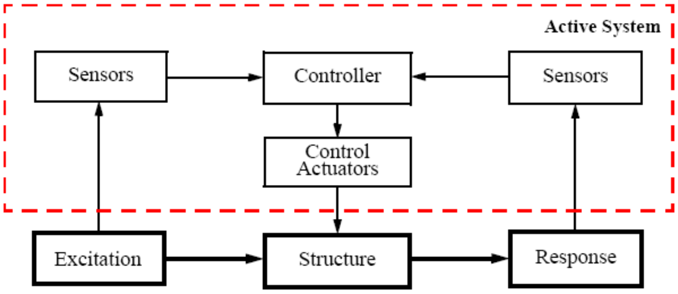
- **General features**
    - Introduce force into the structure thus require an external power supply to operate.
    - Possess feedback systems which allow them to respond proportionally to different situations.
    - Consist of
        - Sensors
        - Central controller(computer)
        - Actuators

3.2. Active Controls

- **Active control process**
  1. The **sensors** detect the response of the structure as well as the characteristics of the ground motion that excites it.
  2. The **computers** process the information from the sensors, compute according to a given algorithm the necessary control forces, and activate the actuators.
  3. The **actuators**, powered by an external energy source, induce the required control forces to counteract the earthquake forces or change the dynamic characteristics of the structure.

3.2. Active Controls

- **Active control process**



Schematic diagram of active control systems.

3.2. Active Controls

- Two major types of active control mechanisms:
  1. External control forces are used directly to balance the earthquake forces.

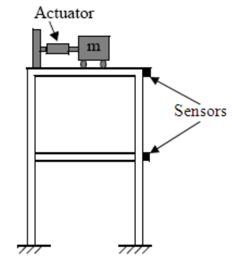
     E.g. active mass dampers, active bracing systems

  2. External control forces are used to change the dynamic properties of the structure so that resonance of the structure with the ground motion is avoided.

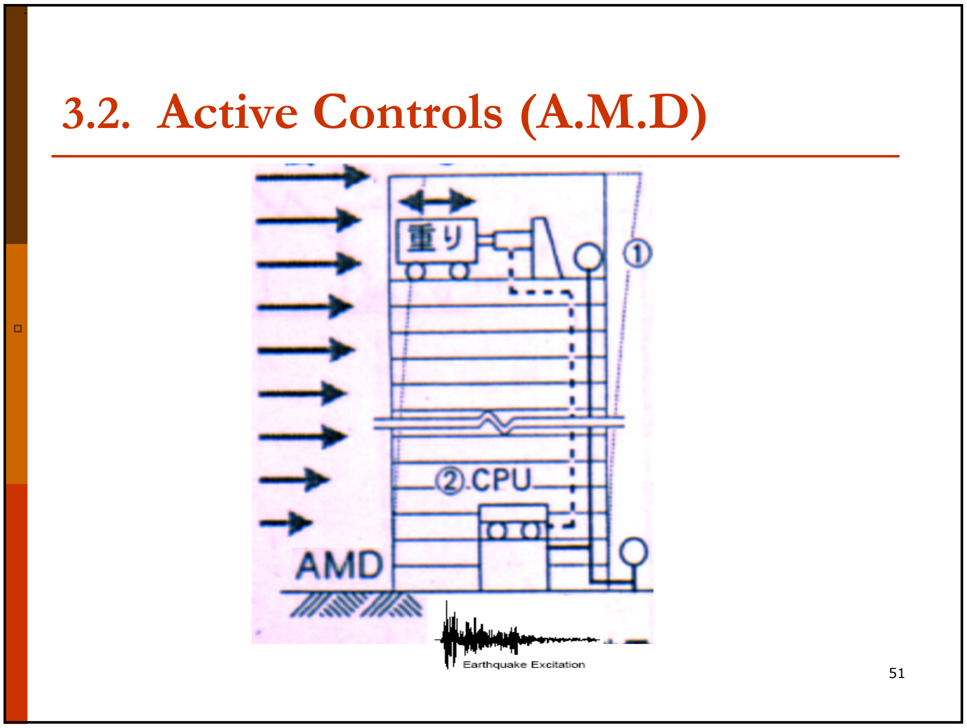
     E.g. active variable stiffness system

3.2. Active Controls (A.M.D)

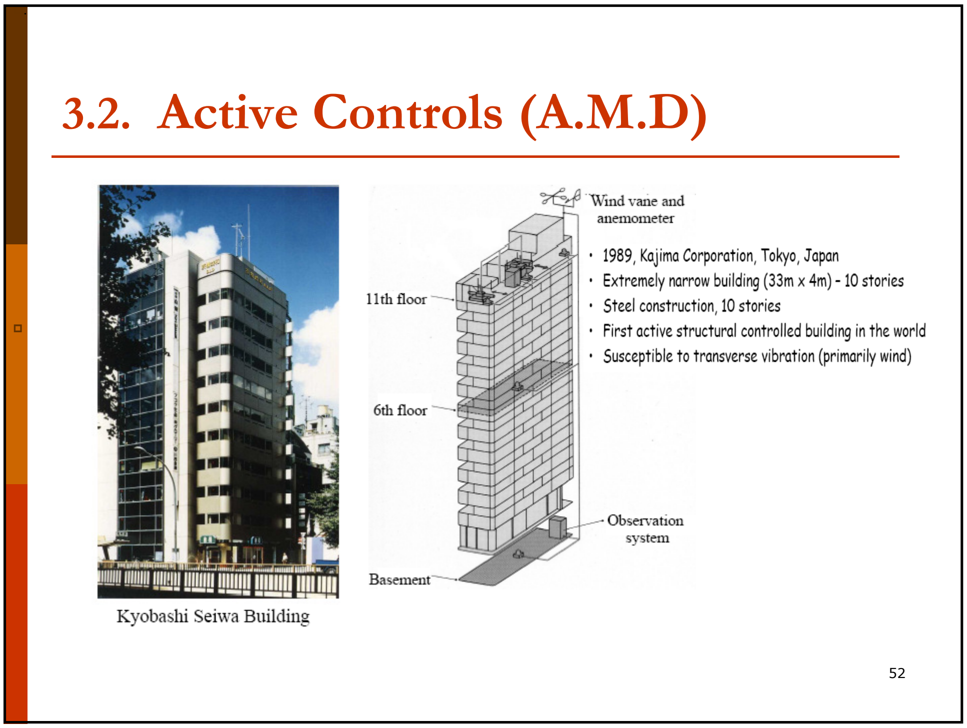
- Active control devices
  - **Active mass damper (AMD)**
    - A small-auxiliary mass (about 1% of the total building mass) that is installed on one of the upper of a building is directly excited by an actuator with no spring and dash pot.



Active mass damper



3.2. Active Controls (A.M.D)



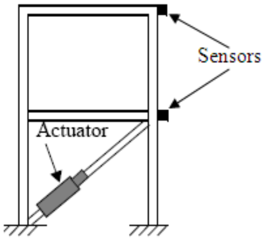
3.2. Active Controls (A.M.D)

Kyobashi Seiwa Building

- 1989, Kajima Corporation, Tokyo, Japan
- Extremely narrow building (33m x 4m) - 10 stories
- Steel construction, 10 stories
- First active structural controlled building in the world
- Susceptible to transverse vibration (primarily wind)

3.2. Active Controls (A.B.S)

- Active control devices
  - **Active bracing systems**
    - consist of a set of pre-stressed tendons or braces connected to a structure, their tensions being controlled by electrohydraulic servomechanisms.



Active bracing system

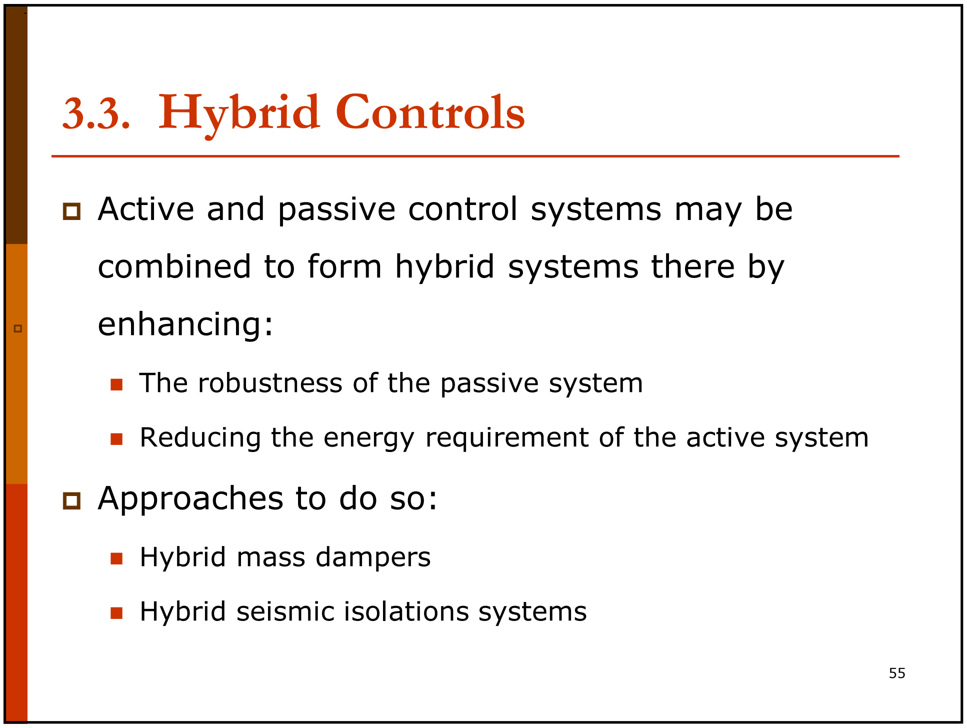
can make use of existing structural members without extensive additions or modifications to the structure.

3.2. Active Controls (V.S.D)

- Active control devices
  - **Active variable stiffness system**
    - by continuously changing the stiffness of the structure, resonance is avoided and the response of the structure is minimized.

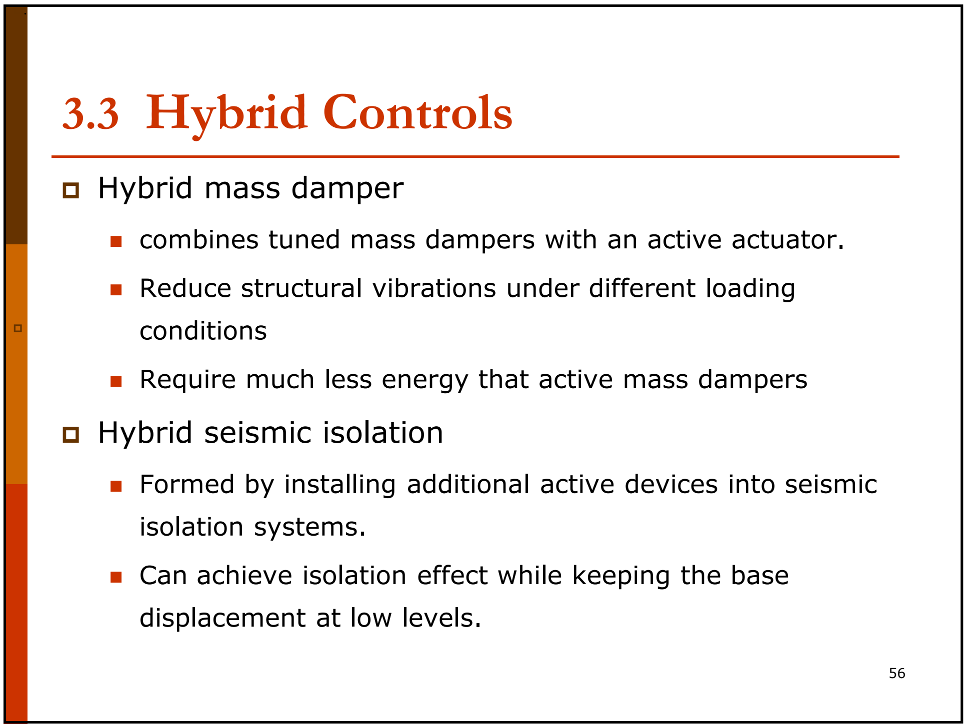
Kajima shake-table building (Kajima KaTRI Center)

Variable stiffness device (VSD) is installed in a brace frame and has 2-states: locked and unlocked



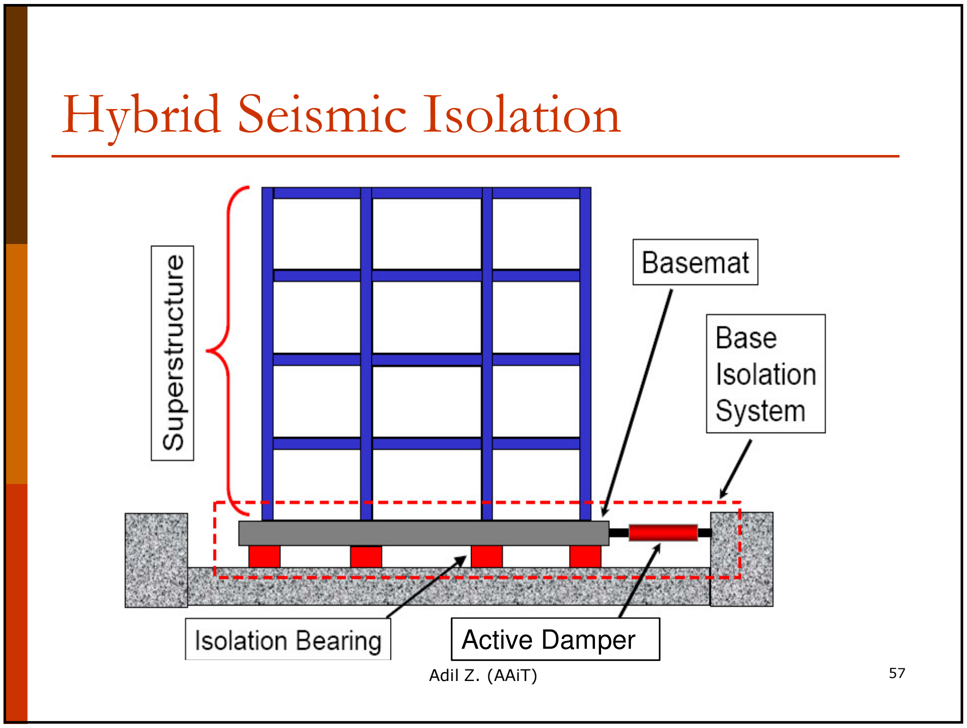
3.3. Hybrid Controls

- Active and passive control systems may be combined to form hybrid systems there by enhancing:
  - The robustness of the passive system
  - Reducing the energy requirement of the active system
- Approaches to do so:
  - Hybrid mass dampers
  - Hybrid seismic isolations systems

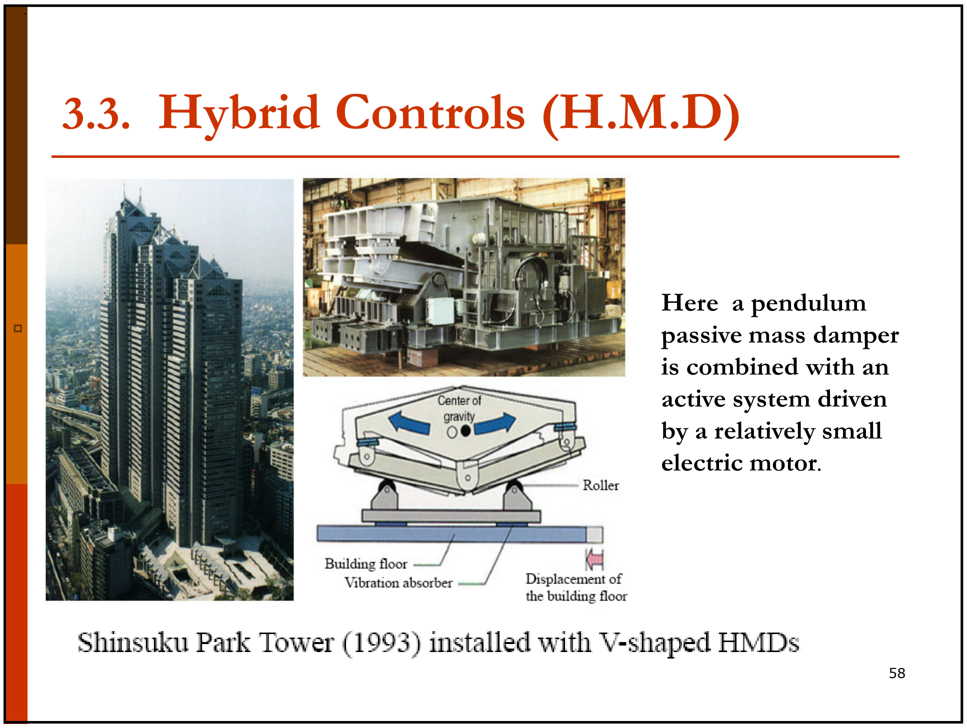


3.3 Hybrid Controls

- Hybrid mass damper
  - combines tuned mass dampers with an active actuator.
  - Reduce structural vibrations under different loading conditions
  - Require much less energy that active mass dampers
- Hybrid seismic isolation
  - Formed by installing additional active devices into seismic isolation systems.
  - Can achieve isolation effect while keeping the base displacement at low levels.



Hybrid Seismic Isolation

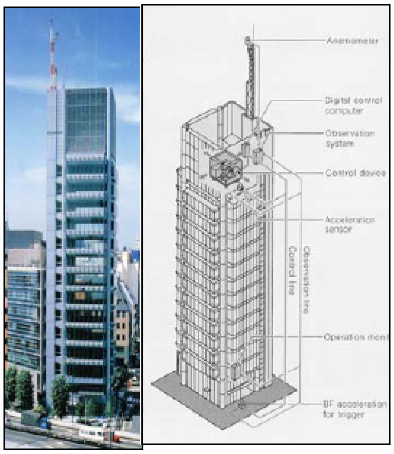


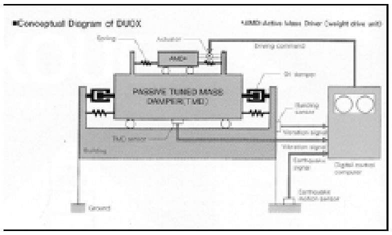
3.3. Hybrid Controls (H.M.D)

Here a pendulum passive mass damper is combined with an active system driven by a relatively small electric motor.

Shinsuku Park Tower (1993) installed with V-shaped HMDs

3.2 Hybrid Controls (H.M.D)





DUOX is another type of HMD
Here small active mass dampers are mounted on a passive tuned mass dampers

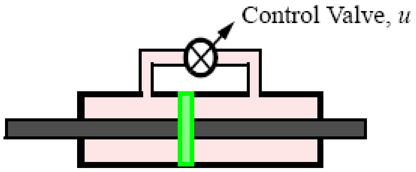
Ando Nishikicho Building (1993, Kajima Corporation, Tokyo, Japan)

3.4. Semi-active Controls

- **General features**
  - The control is produced by the movement of the structure but is regulated by an external energy source.
  - Like a **passive control device** generate reactive forces as a result of the motion of the structure and cannot add energy to the structural system.
  - Like an **active control device** generate an appropriate signal using feedback measurements of the excitation.
  - Only a small external power source is required for their operation.

3.3. Semi-active Controls (V.O.D)

- **Semi-active control devices**
  - **Variable orifice dampers**
    - Can achieve variable damping by changing the hydraulic fluid flow resistance using an electromechanical variable orifice.



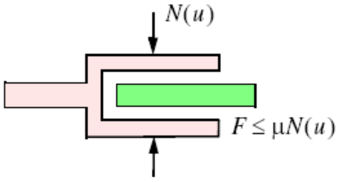
variable orifice damper

3.3. Semi-active Controls (V.O.D)

Variable orifice dampers installed on the I-35 Walnut Creek Bridge.

3.3. Semi-active Controls (V.F.D)

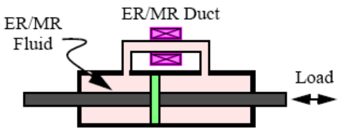
- **Semi-active control devices**
  - **Variable friction dampers**
    - Dissipate vibration energy in a structural system by utilizing force generated by surface friction.
    - Consist of a preloaded friction shaft rigidly connected to the structural bracing.



variable friction damper

3.3. Semi-active Controls (C.F.D)

- **Semi-active control devices**
  - **Controllable fluid dampers**
    - Consist of controllable fluids in a fixed-orifice damper.
    - More reliable than the previous semi-active devices as they don't employ electrically controlled valves.
    - Utilize either electrorheological (ER) fluids or magnetorheological (MR) fluids.



controllable fluid damper

3.3. Semi-active Controls

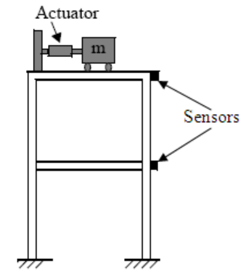
- **Semi-active control devices**
  - **Magneto/Electro-rheological fluids**
    - Special fluids which contain very small polarizable particles.
    - Applied field that is magnetic/electrical field changes mechanical properties of such fluids i.e. viscosity of the fluid can be changed very quickly form a liquid to a semi-solid and vise versa.
    - During an earthquake, sensors in the building send signals to the computer system to magnetize the coils, which turns these fluids to semi-solid.
    - Although the discovery of such fluids dates back to the 1940s, only recently have they been applied to civil engineering applications.

3.3. Semi-active Controls

- **Comparison of ER and MR fluids**
  - ER fluids
    - Have limited yield stress (3 to 3.5 KPa)
    - Affected by impurities
    - Require relatively high voltage(~4000v)
  - MR fluids
    - Have a 50 to 100 KPa maximum yield stress
    - Are not affected by most impurities
    - Can be controlled with a low voltage (~12-24 v)
- Hence, MR fluids are practically feasible

3.3. Semi-active Controls

- **Semi-active control devices**
  - **Semi-active tuned mass dampers**
    - motion of the damping mass can be controlled



Semi-active tuned mass damper

4. Summary

- **Passive controls**
  - **Merits**
    - Tend to be very simple systems.
    - Do not need any external input of energy to work.
    - Usually compact and non-invasive to architectural spaces.
    - Relatively inexpensive solution to reducing structural vibrations.
  - **Demerits**
    - Unable to adapt to changing situations.
    - Limits exist on the amount of control attainable.

4. Summary

- **Active controls**
  - **Merits**
    - Able to adapt to changing situations.
    - Capable of providing excellent control effects if properly used.
  - **Demerits**
    - Rely on an external power supply which may fail during the earthquake.
    - Relatively expensive due to the use of modern technology.
    - Maintenance of the system is very important.
    - Possibility of time-delay between reading the information from sensors and the application of the actuator forces.

4. Summary

- **Semi-active / Hybrid controls**
  - **Merits**
    - combine the best features of active and passive systems.
    - require small amount of external power for the operation.
  - **Demerits**
    - Not as reliable as passive system but more so than an active system.
    - Relatively expensive due to the use of modern technology.

That is all for now

Refer to:

1. *Chopra's Structural Dynamics book*
2. *Dorwick's EQRDesign & Risk Reduction*
3. *Chen & Scawthorn's EQ Handbook*

for more information